

# SUBSURFACE DRIP IRRIGATION SYSTEM DESIGNED FOR RESEARCH IN ROW CROP ROTATIONS

R. B. Sorensen, F. S. Wright, C. L. Butts

**ABSTRACT.** A subsurface drip irrigation (SDI) system was designed and installed to conduct long-term research on peanut (*Arachis hypogaea*) and associated cotton (*Gossypium hirsutum*) and corn (*Zea mays*) crop rotations. The objectives were to design a subsurface drip irrigation system for a long-term irrigation research project, describe potential versus actual expenses of the designed system, and to show SDI system performance for irrigation scheduling in row crop (peanut) production. The system includes two thin-wall drip tape lateral spacings buried 30 to 35 cm below the soil surface, three irrigation levels, and five crop rotations replicated three times in a randomized block design. Each mainline branches into two field mainlines reducing the number of flow meters and injector pumps by half. Potential evapotranspiration ( $ET_o$ ) was estimated using the modified Jensen-Haise equation adjusted for location conditions. Irrigation treatments of 100, 75, and 50% were based on the crop water use and crop coefficient curves. Irrigation water was applied on a daily basis. A programmable logic controller (PLC) acquired hourly weather parameters, flow data, and controlled the total system. A well water source was used with a separate pump to supply water to the drip irrigation system. The SDI system operated and delivered water to the field crops within the design constraints. Each field mainline took about 6 min to pressurize. There were slight fluctuations in pressure and flow rate for short time durations as valves turned off and on. About \$9600 was saved by using a branched design of one flow meter and injector pump per line when compared with a non-branched system. Irrigation plus rainfall supplied just over 100% of the water required for peanut. The other irrigation treatments supplied 75 and 53% of the irrigation water required. Overall, this SDI system was used to efficiently supply water to a row crops in southwest Georgia.

**Keywords.** Irrigation water management, Subsurface drip, *Arachis hypogaea*, *Zea mays*, *Gossypium hirsutum*.

Subsurface drip irrigation (SDI) has the potential to provide consistently high yields with nonuniform precipitation while conserving soil, water, and energy. Other benefits include precise placement of water and chemicals, low labor requirements, and reduced water runoff and erosion. These SDI systems have the capability of frequently supplying water to the root zone while reducing the risk of cyclic water stress that is typical of other irrigation systems. Also, SDI systems are adaptable to variations of field shape making them an important consideration in the southeast. However, SDI systems comprise less than 1% of the irrigated acreage in the United States (*Irrigation Journal*, 1997). Various researchers have shown that crop yield and quality can be increased using SDI on tomato (Bogle et al., 1989; Camp et al., 1989), cotton (Bucks et al., 1988; Henggeler, 1988), and corn (Mitchell, 1981; Mitchell and Sparks, 1982; Powell and Wright, 1993).

Drip tube laterals have been installed at 0.2- and 0.3-m soil depths (Bucks et al., 1981; Tollefson, 1985; Phene et al., 1987; Camp et al., 1989) on cotton, corn, fruits, and vegetables. Drip laterals have been spaced at 1, 2, and 3 m apart with yields decreasing as lateral spacing increased to greater than 2 m (French et al., 1985; Lamm et al., 1992; Powell and Wright, 1993; Camp et al., 1997).

Generally, drip (surface or subsurface) irrigation has been used on high value crops (Nakayama and Bucks, 1986; Clark and Smajstrla, 1996). Interest in drip irrigation for row crops has increased over the past 10 years. Manufacturers of drip systems have improved the quality of thin-wall drip tube, system components, and emitter designs for uniform water distribution. The thickness of drip tube range from 0.102 to 0.381 mm (4 to 15 mil). The thicker-walled drip tube can be buried and used for 15 years or longer before replacement (Powell and Wright, 1993).

Installing the thin-wall drip tube 31 to 36 cm (12 to 14 in.) below the soil surface places the water in the root zone where plants can use it efficiently. The drip tube is also deep enough that most surface tillage can be used without disturbing drip tube placement. Advantages of applying water by this method include: application of water at low operating pressure, minimal soil surface evaporation losses, maintenance of a uniform soil water content, and supplying the plant nutrients as needed during the growing season. These factors conserve energy and water and reduce the

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potential of polluting the environment while providing the plant–water needs (Roberts and Styles, 1997).

The design of an SDI system for conducting research compared to irrigating a large area farm system is different in component size, water flow rate, field layout, operation, and management due to the numerous combinations of irrigation water treatments, crop rotations and research requirements. Therefore, the purpose of this article is: 1) to present the design of a subsurface drip irrigation system installed for a long-term irrigation research project, 2) describe potential versus actual expenses of the designed system, and 3) to show SDI system performance for irrigation scheduling in peanut crop production.

## MATERIAL AND METHODS

### GENERAL FIELD DESCRIPTION

The SDI system described herein is used for a long-term research project directed by U.S. Department of Agriculture, Agricultural Research Service, National Peanut Research Laboratory, Dawson, Georgia. The site was located in Terrell County near Sasser, Georgia, on a Tifton sandy loam soil (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with 2–5% slope. A 6.8-ha (15-ac) area of leased land was divided into four equal areas referred to as tiers [1 ha (2.5 ac)]. There were alleyways between tiers and at the sides and crop row ends for equipment turn areas. Three tiers were used for the SDI irrigation treatments and one tier was assigned as a sprinkler treatment. Only the SDI system and treatments will be described. Each SDI tier [38 × 274 m (125 × 900 ft)] was randomly assigned an irrigation level. An SDI tier consisted of three blocks (replications), five crop rotations, and two thin-wall drip lateral spacings for a total of 30 plots per tier (fig. 1). The irrigation levels were 100, 75, and 50% of estimated crop water use (irrigation procedure described below).

The five crop rotations include continuous peanut, cotton, and/or corn rotated with peanut at two, three, and four-year intervals. All crops were planted on a 0.91-m (3-ft) row spacing. The two drip tube lateral spacings include drip tube installed underneath each crop row [0.91 m (3 ft)] and in alternate crop row middles [1.83 m (6 ft)]. The narrow drip

tube lateral subplots (0.91 m) had six laterals installed, one under each row in one subplot (6 crop rows). The wide drip tube lateral subplots [1.83 m (6 ft)] had five laterals installed in alternate crop row furrows (middles) in one subplot (10 crop rows). Each subplot was replicated three times for a total plot area of 0.06 ha (0.15 ac) for each narrow (0.91-m drip tube spacing) plot and 0.1 ha (0.25 ac) for each wide plot (1.83-m drip tube spacing).

Each subplot was connected to a PVC supply field mainline and to a flush mainline buried 38 to 51 cm (15 to 20 in.) deep. One field mainline PVC pipe supplied water to three subplots, one in each block. A total of 10 field mainlines per tier or 30 field mainlines for the three tiers were used. Each subplot had a PVC manifold [2 cm (0.75 in.) Schedule 40 PVC pipe] at the supply and the flush end to connect the thin-wall drip tube to PVC pipe. A 2-cm (0.75-in.) PVC pipe-to-drip tube adapter with a lock ring was used to connect the thin-wall tubing to the PVC manifold. Replicate subplots were connected to the same field mainline and flush mainline and the flush water was discharged at the lower end of the field.

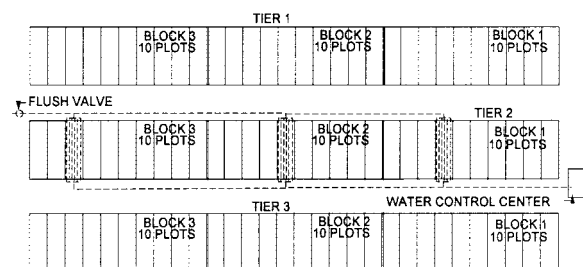
The thin-wall drip tube (Super Typhoon, Netafim Irrigation, Inc., Fresno, Calif.; [www.netafim-usa.com](http://www.netafim-usa.com)) had wall thickness of 0.254 mm (10 mil) and emitters spaced every 46 cm (18 in.) with a flow rate of 1.5 L h<sup>-1</sup> (0.4 gph). All thin-wall drip tubing was buried 31 to 36 cm (12 to 14 in.) using a modified ripper shank.

The water source was a 10-cm (4-in.) diameter well, 67 m (220 ft) deep, with a 3.7-kW (5-hp) submersible pump delivering about 265 L m<sup>-1</sup> (70 gpm) to a 4540-L (1200-gal) vertical stainless steel reservoir tank.

### DESIGN OF THE DRIP IRRIGATION SYSTEM

Design constraints defined for distribution of water to the plots were: (1) locate the water control center for all plots at one location, (2) simultaneously operate as many mainlines as the water supply would allow, (3) use various PVC pipe sizes for the supply mainline so the total pressure loss from the water control center to any sub-plot was less than 7 kPa (1 psi), (4) minimize the number of flow meters required for monitoring the flow of water to each plot, (5) include components needed to automate the application of water amendments, (6) provide for automatic injection of nutrients for each crop as needed, and (7) apply daily irrigation treatments based on environmental conditions. Irrigation treatments were based on the water consumptive use or a fraction thereof as normally applied by overhead sprinkler systems for peanut, corn, and cotton crops (Stansell et al., 1976; Harrison and Tyson, 1993).

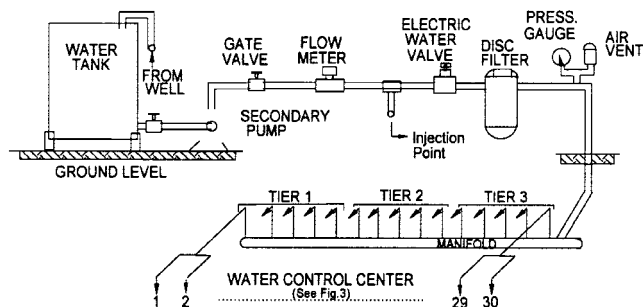
The water control center was placed at the highest elevation in the field (fig. 1). Water from the deep well was pumped to the reservoir tank and from the reservoir tank to the control center (fig. 2). Water flow into the reservoir tank from the deep well was controlled by two level control relays (Model 409, Time Mark Corp., Tulsa, Okla.; [www.time-mark.com](http://www.time-mark.com)), and a switch probe. The switch probe consisted of two contact points, one at the low water level and the other at the high water level. The switch probe and relays would open and close a 24-VAC water valve in a 5-cm



**Figure 1.** General field layout showing, three tiers [38 m × 274 m (125 × 900 ft)], three blocks/tier, 10 plots/block (five crops and two lateral spacings), a total of 90 plots. Example: in Tier 2, the field mainline is connected to three subplots, one in each block, which received the same water treatment.

(2-in.) PVC pipe from the deep well. These relays and contact points prevented short cycling of the submersible deep well pump. No back flow prevention device was required because the reservoir tank was isolated from the well water source. The well water source was isolated from the subsurface drip system for two reasons: 1) to prevent contamination from chemicals (nutrients or pesticides) injected into the drip system, and 2) to minimize pressure fluctuations on the pressure regulators operating at 83 kPa (12 psi) on the field mainlines.

Water was pumped from the reservoir tank with a 1.5-kW (2-hp) centrifugal pump into the control center mainline [5-cm (2-in.) PVC pipe] which consists of a gate valve, vortex flow meter (Fluidyne Model 1100, Engineering Measurement Co., Longmont, Colo.; [www.emcoflow.com](http://www.emcoflow.com)), injection point, electric water valve, 5.0-cm (2-in.) disc filter (Netafim Irrigation, Inc.), 0- to 700-kPa (100-psi) pressure gage, 2.5-cm (1-in.) air vent, and 5-cm (2-in.) PVC manifold (fig.2). The centrifugal pump output was 227 L m<sup>-1</sup> (60 gpm) at 156 kPa (23 psi) to a maximum of six field mainlines lines. The mainline flow meter [5 cm (2 in.)] has a digital cumulative volumetric readout (gal) as part of the



**Figure 2.** Schematic of the main water supply mainline and components that connect to the water control center. The water control center (15 supply mainlines) branches one supply mainline into two field mainlines (30 field mainlines).

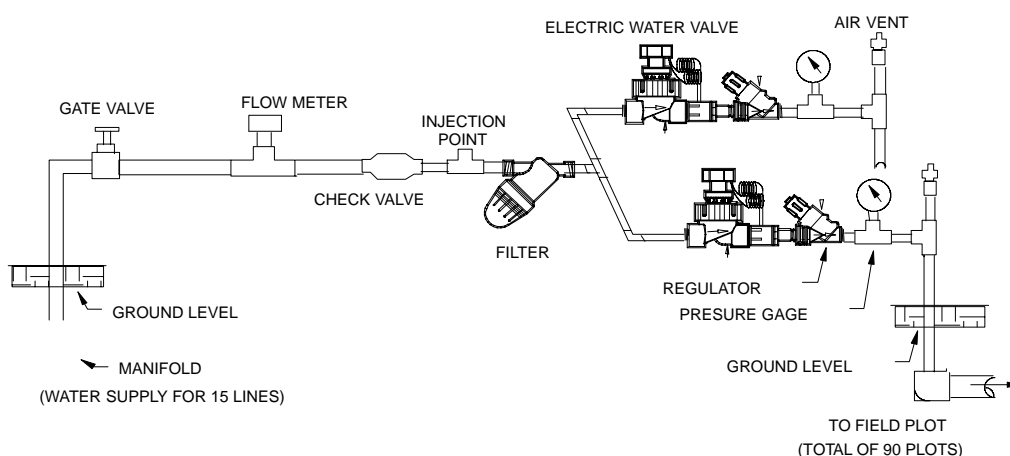
flow meter, and a 4 to 20 mA analog signal [0 to 473 L m<sup>-1</sup> (0 to 125 gpm)] for continuous electronic monitoring.

The 5-cm (2-in.) manifold had 15 control mainlines [2.5-cm (1-in.) PVC pipe] which exit the underground manifold and branched into two separate field mainlines (fig. 3) for a total of 30 field mainlines. Branching the mainline into two separate field mainlines allowed the use of one gate valve, flow meter, check valve, injection point, and disk filter. The PVC pipe was reduce to 2 cm (0.75 in.) diameter prior to the disk filter. Following the disk filter, the mainline branched into two separate field mainlines. Each field mainline includes an electric water valve, low flow 83-kPa (12-psi) pressure regulator, 0- to 207-kPa (30-psi) pressure gage, and an air vent before exiting to one of the 30 field mainlines (fig. 3).

The supply mainline PVC pipe was sized to deliver water with a friction loss less than 7 kPa (1 psi) for each field mainline [36 L m<sup>-1</sup> (9.5 gpm)] for the total length of the tier. The following PVC pipe diameters were selected for the field mainlines: from the control center to the first subplot in Block 1, 3.8 cm (1.5 in.); from Block 1 to the next subplot in Block 2, 3.2 cm (1.25 in.); and from Block 2 to the last subplot in Block 3, 2.5 cm (1 in.).

The narrow lateral spacing (0.91 m) plots required about 38 L m<sup>-1</sup> (10 gpm) per field mainline, whereas, the wide (1.83 m) lateral spacing plots required about 32 L m<sup>-1</sup> (8.4 gpm) per field mainline. Different irrigation runtimes were calculated for each plot determined by potential evapotranspiration (ET<sub>o</sub>), crop coefficient, plot size, and irrigation treatment (described below).

Programmable logic control (PLC) modules were used to monitor on-site weather parameters, estimate ET<sub>o</sub>, calculate irrigation runtimes, and chemical injection runtimes for each of the 30 field mainlines. The PLC was used to control the electronic valves, injector pumps, irrigation pumps, and monitor flow rates and shut the system off in emergency situations (high flow indicative of broken mainline or zero flow indicating no inflow of water).



**Figure 3.** Irrigation components for one of 15 mainlines connected to the water control center which supplies water to two field mainlines. During irrigation only one field mainline of any pair is on at a time. Only 5 or 6 of the 30 field mainlines are on at one time. The SDI system irrigates all the odd numbered field mainlines then irrigates the even numbered field mainlines.

Irrigation runtimes were calculated daily using a modified Jensen–Haise equation adjusted for local conditions. Estimated  $ET_0$  was multiplied by a crop coefficient (for peanut see, Harrison and Tyson, 1993; Stansell et al., 1976) to estimate the depth of water to apply to each crop based on crop specie and plot area. Irrigation depth values were then converted to time values using design flow values for each plot area, i.e. narrow lateral spacing (0.91 m) or wide lateral spacing (1.83 m). The maximum depth of water allowed for peanut was  $6 \text{ mm d}^{-1}$  (0.23 in./d) which is about  $1.0 \text{ mm d}^{-1}$  (0.04 in./d) greater than the maximum crop water use for peanut described by Stansell et al. (1976). A minimum value of water to apply was set at  $1.0 \text{ mm d}^{-1}$  (0.04 in./d) unless rainfall exceeded the estimated irrigation depth. When rainfall exceeded irrigation depth, the drip system would not be activated for that day. The maximum irrigation depth value was adjusted for each crop specie not to exceed the maximum water required (documented literature values) by more than 15%.

Field mainlines and associated electronic valves were number consecutively from 1 to 30. By design the odd numbered valves were the 0.91-m spaced laterals, while the even number valves were the 1.83-m spaced laterals. During an irrigation cycle, the PLC turned on and off the odd numbered valves, 1 to 29, then stepped through all of the even numbered valves 2 to 30. Branching the mainline into separate field mainlines required PLC programming such that both valves associated with one mainline from being turned on at the same time. Turning on both an odd and even electric solenoid valve connected to the same mainline would irrigate both a narrow and wide lateral spacing. Irrigation flow data would be collected but with no way to separate how much water went to each plot.

The irrigation runtime for each field mainline could differ because of crop type, crop age, or crop area. The PLC system was programmed to turn on and off five to six field mainlines and simultaneously record flow data. During startup, only one field mainline would come on at a time using an approximate 3-min delay between each electric solenoid valve start. After the first initial set of valves were started, when a valve turned off there was an approximate 2-min delay before the next valve in sequence would be turned on.

Liquid nitrogen fertilizer was applied to corn and cotton crops using one injection pump (Model C15N302X, Blue–White Industries, Westminster, Calif.; [www.blwhite.com](http://www.blwhite.com)) per mainline (before branching into separate field mainlines, see fig. 3). The injection point was installed before the disk filter to clean out any foreign particles in the liquid fertilizer. Injection pumps were actuated daily by the PLC. Injection times for corn and cotton will not be discussed in this article.

## RESULTS AND DISCUSSION

### SYSTEM OPERATION

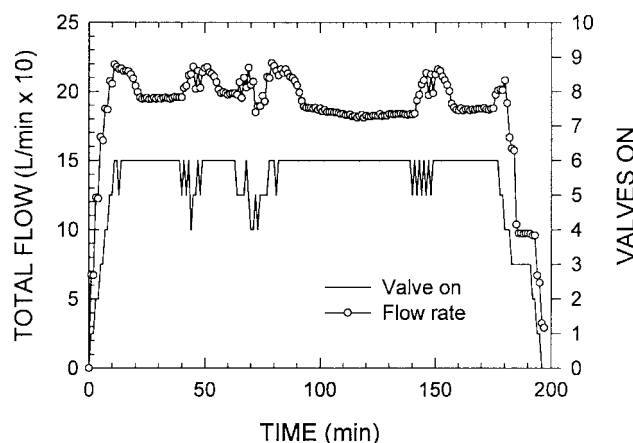
The 1998 growing season was the first operational year for this SDI system. Unfortunately, there were some hardware and software problems that needed to be corrected. Hardware

problems consisted of improper electrical connections and mismatched electrical components. One major software problem consisted of PLC programming to correctly log flow data from one flow meter on the mainline connected to two solenoid valves. Once these problems were corrected the system was fully operational by the middle of June. The system worked well until the middle of July when lightning disabled the electronic controller. The system was operated manually until replacement components were installed.

The SDI system functioned quite well during the 1999 growing season with only a couple of short duration “down times” due to software errors and about a week long “downtime” due to lightning and equipment replacement. Surge protection equipment was added to minimize equipment loss and system downtime caused by lighting.

When a field mainline valve was first opened a higher flow rate than designed was observed for about 6 min or until all of the field mainlines that were turned on had fully pressurized. If two or more field mainlines were turned on within 6 min of each other, the average flow rate decreased in field mainlines that had previously reached pressurized flow rates. These fluctuations were for short duration and probably did not adversely affect the total water applied to any of the plots.

Output data were collected at 1-min intervals to determine average flow rate after mainline pressurization and length of time to pressurize field mainlines. The total water flow and number of valves turned on were recorded (fig. 4). Fluctuations in water flow occurred as an electric valve was opened or closed during one daily irrigation cycle. After observing the system for a few days, only hourly output data were collected. Visual observation of pressure gauges indicated a slow increase in pressure in each field mainline after the electric valve opened. While each field mainline was filling, the pressure would vary between 70 and 103 kPa (10 and 15 psi) depending on the number of field mainlines operating (one to six field mainlines). When the water reached a steady flow in all the field mainlines that had been turned on, the pressure would stabilize at about 83 kPa (12 psi). Fluctuations in water flow rate and variations in



**Figure 4.** Total flow and number of valves operating versus time for one daily cycle. The SDI system will only irrigate six of the 30 field mainlines at a time. The electronic controller cycled through the odd field mainlines and then the even field mainlines.

pressure that occurred for short durations as valves were turned off and on, were not a major concern when considering the total runtime for each valve and total operation of the drip system. Runtimes for the 0.91-m lateral spacing ranged from 10 to 100 min while runtimes for the 1.83-m lateral spacing ranged from 10 to 190 min.

The automatic controller and water control components performed exceptionally well through two irrigation seasons. Software problems required some reprogramming, while hardware problems were repaired as quickly as possible. The PLC ladder logic software, BASIC software, PLC modules, water control components, and SDI system provided a wide range of flexibility for irrigation and chemigation treatments. The physical layout of three tiers and five crop rotations provides added flexibility for future research studies involving crop rotation/water/nutrient/crop yield relationships.

Except for a small amount of dry granular fertilizer applied pre-plant with a tillage operation, liquid fertilizer solution (32% N diluted to various concentrations as needed) was applied to corn and cotton through the SDI system. Injection pumps were actuated by the PLC.

### SYSTEM ECONOMICS

Major cost (using 1998 cost data) to the SDI system were electronic flow meters, injector pumps, and field mainline PVC pipe. Branching the mainline into two field mainlines reduced the number of flow meters and injector pumps by half. The electronic flow meters cost about \$6450 for the 15 flow meters. This cost would double if one flow meter was used for each of the 30 field mainlines.

The crop rotations were designed such that at no time during the length of the project would corn and cotton exceed three of the five crop rotations. Therefore with branching of the mainline, the maximum number of injector pumps needed in any one year would be nine. These nine injector pumps cost over \$2160. This cost would double if one injector pump was used for each field mainlines (18 injector pumps) assigned to corn or cotton.

Increasing the number of injector pumps and flow meters would require the purchase of more modules for the PLC. That would increase the cost of the control system by about \$2000.

Installing a system with only one size pipe would be less complicated to install than with various PVC pipe sizes. Therefore, it was suggested to use the same size PVC pipe for the supply field mainlines. As designed, an average field mainline would require about 700 feet of PVC pipe at a cost of \$115 per field mainline using only the 3.8-cm (1.5-in.) diameter pipe. Reducing pipe sizes at each block decreased the cost to about \$77 per field mainline.

System cost was significantly reduced because flow meters and injector pumps were two of the most expensive components in the water control center. Programming the PLC was more complex using one flow meter/injector pump per mainline than programming one injection pump/flow meter per field mainline. Overall, branching the mainline and reducing the number of flow meters and injector pumps by half and also reducing the field mainline PVC pipe size at

each block showed an estimated dollar savings to the overall project of about \$9600. This amount does not include the \$2000 savings for not using extra PLC modules required for more hardware.

### WATER APPLIED AND GENERAL MANAGEMENT

Figure 5 shows the cumulative  $ET_o$  estimated by the modified Jensen-Haise, cumulative water required by a peanut crop (Stansell et al., 1976), and cumulative irrigation water applied for the three irrigation treatments. These data show that water required by peanut was about 530 mm (21 in.). Total water applied at 100% irrigation was 356 mm (14 in.), rainfall was 225 mm (8.8 in.), such that the total water applied to the 100% irrigation treatment was 567 mm (22 in.) or essentially the depth required for peanut. The other two irrigation treatments received water at designed levels of 75 and 53% of the total irrigation water applied.

The deep well water quality was such that minimal amendments were required for the SDI system. The main disk filter and individual field mainline disk filters were cleaned about every two weeks when the system was first operational. During the first month of operation, very little foreign material was collected in the filters, thus, the 2-week schedule was discontinued and a 6- to 8-week schedule was instituted. Flushing the SDI system followed this same pattern.

Thin-wall drip tube manufacturers recommend the use of amendments to reduce algae growth and root penetration. Chlorine was applied at 2 to 5 mg L<sup>-1</sup> (2 to 5 ppm) at monthly intervals. Chlorine concentration was raised to 20 mg L<sup>-1</sup> (20 ppm) at the beginning and end of the growing season. Trifluralin ( $\alpha, \alpha, \alpha$ -trifluoro-2,6-dinitro-N-N-dipropyl-p-toluidine) was added to the SDI system at 20 to 25 mg L<sup>-1</sup> (20 to 25 ppm) at the beginning and end of the irrigation season

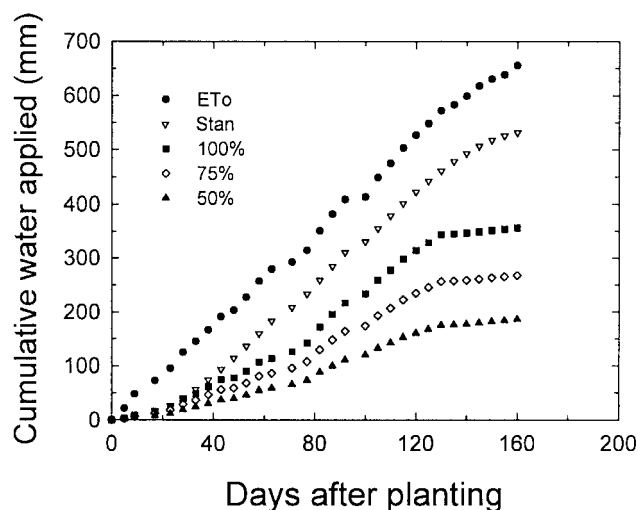


Figure 5. Cumulative water required ( $ET_o$  and Stan) and applied (irrigation level 100, 75, and 50%) during the 1999-growing season.  $ET_o$  is the potential evapotranspiration estimated using the modified Jensen-Haise equation. "Stan" is the crop water use described by Stansell et al. (1976). The applied irrigation levels are 100, 75, and 50% of the Stan curve minus daily rainfall. Rainfall during the growing season was 225 mm (8.8 in.).

to control root intrusion into emitters. The SDI system was flushed prior to injecting chlorine and Trifluralin at the end of the season. The system was not flushed after injecting these chemicals, allowing the chemicals to stay in the drip tubes as long as possible.

After the 1998 growing season and prior to the 1999 growing season, repairs were needed on the thin-wall drip tubing due to rodent and insect damage. The rodent damage was easy to identify, however, we do not know what insect was making holes in the drip tube and samples of the tape have been sent to the drip tube manufacturer and the extension service for possible insect identification. Until a positive identification is secured, the recommendation was to add a general insecticide to the drip system. Chlorpyrifos [*O,O*-diethyl-*O*-(3,5,6 trichloro-2-pyridinyl) phosphorothioate] was injected every 3- to 4-week intervals to the drip system at 20 mg L<sup>-1</sup> (20 ppm). Since the addition of this pesticide, there has been a reduction in both rodent and insect damage to the drip tubing.

## CONCLUSIONS

Each field mainline takes about 6 min to pressurize and slightly longer depending on the number of mainlines and time intervals the electric valves are activated. A slight fluctuation in pressure and flow rate occurs as valves are turned off and on during an irrigation cycle.

The design of one flow meter and chemical injection pump per two field lines was feasible and cost effective. This design increased the difficulty of the software program but saved about \$9600 by using half the flow meters and chemical injection pumps.

The SDI system functioned properly by applying the needed water on a daily basis. During the 1999 growing season, irrigation water applied was 356 mm (100%), 268 mm (75%), and 187 mm (50%). Total water required by the peanut crop was estimated at 532 mm. Added rainfall brought these totals to 581 mm (100%), 493 mm (75%), and 412 mm (50%).

Lightning caused some problems with the PLC controller, but added surge protection devices attached to the weather sensors seem to reduce these problems. Rodent and insect damage occurred with the thin-wall drip tubing but injecting chlorine and pesticides seemed to correct these problems. SDI system management, irrigation control, and data collection has been successful using PLC technology. Overall, the SDI system has operated and delivered water to peanut within design constraints.

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